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THE ROLE OF THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY AS IT RELATES TO PRODUCT DATA DRIVEN ENGINEERING

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ABSTRACT

The various activities of the National Institute of Standards and Technology (NIST) in the development of a Product Data Exchange Standard (PDES) will be discussed. The NIST activities will be described in terms of the unique position that the agency has in the area of standards and technology development in the United States. The NIST has an active role in participating in the formal development of the PDES standard. In addition, NIST is engaged in research & development programs involving information technologies necessary for implementing PDES and engineering technologies that make use of product data. Specific applications such as mechanical part fabrication are being used to provide a testbed for the validation and verification of PDES. The paper addresses how PDES can be used to implement needed technologies such as concurrent engineering that will improve American Industrial competitiveness. The combination of PDES implementations with concurrent engineering is called in this paper "Product Data Driven Engineering."

Work related to PDES is conducted by many organizations at NIST. The organizations include the Center for Building Technology with interests in the architecture, engineering, and construction area; the National Computer Systems Laboratory with interests in testing and validation; the Center for Electronics and Electrical Engineering with interests in the behavior modeling of electronic components; and the Center for Manufacturing Engineering (CME) with an overall interest in the product life-cycle. This paper will primarily address the scope of the CME efforts, and within CME, the Factory Automation Systems Division (FASD).

INTRODUCTION

To improve competitiveness and be able to manufacture world-class products, there is a broad class of actions that can be taken, such as management procedures, design and manufacturing technologies, and methods for the entire engineering life-cycle. However, none of these actions will ultimately make a significant difference, unless the information required to manufacture and support a product is managed effectively.

Information about a product starts with the customer requirements. These requirements are converted into a product

design that will produce a product to meet the perceived requirements. The design data is then made available to the manufacturing area where a plan is created for defining the steps in the actual generation of the product. Both the design and manufacturing information must be made available to the quality assurance and inspection teams. Once the product is produced and delivered, the information must be maintained so that the logistic support staff can manage the inventory and servicing of the product. The collection of processes (e.g. design) is called the "Product Life-Cycle." The information generated during the life-cycle is inter-related. The problem is that each process step involves a different view of the information in the way it is presented and managed. This problem is compounded by the fact that information must be shared by different companies, each of whom has their own unique way of managing information.

The solution to this information management dilemma is the use of standards that are agreed upon by the community of manufacturers. Standards allow the whole community to share information in a manner that has common agreement. There are already a collection of standards that address the information exchange issue. These include standards for text, graphics, and drawings. They also include standards for database query languages and for communication network protocols. A new standard is needed, based on these generic data exchange standards, that can be applied specifically by the manufacturing community to provide for the exchange of product data within and between companies.

A standards development led by the IGES/PDES Organization[1] is called Product Data Exchange Specification (PDES). The goal of the PDES project is to create a standard for information that represents the life-cycle of a product in the neutral form of a computerized product model.

At present, the IGES/PDES Organization has submitted a draft proposal of PDES to the ISO TC184/SC4/WG1 for consideration[2]. There are many important technical issues that must be resolved if PDES is to become a standard.

This paper describes the technical and administrative issues associated with PDES as it relates to the role of the National Institute of Standards and Technology (NIST). In the Background section, the history of NIST as a standards organization and as a technical contributor to manufacturing is described. In the Engineering Research Paradigm section, the emerging new role of NIST, based on the Omnibus Trade and Competitiveness Act of 1988 [3], is described. In the Product Data Driven Engineering Paradigm section, the NIST strategy for PDES implementation is defined. In the Projects Description section, the projects undertaken by the Factory Automation Systems Division are described in terms of meeting the PDES goals. In the last

section, Future Directions, the NIST plans as relates to Product Data Driven Engineering for the next several years are discussed.

BACKGROUND

The National Institute of Standards and Technology (formerly the National Bureau of Standards) was founded in 1901. Its mission was to maintain the weights and measures standards relating to the entire spectrum of commerce requirements. Over the years, NIST has developed a recognized expertise in science and engineering technologies that has been made available to the public through publications and direct interaction with research institutions from government, industry, and university environments. NIST is called upon by Congress, the administration, industrial organizations, product consumer organizations, and academic institutions to serve in special capacities based on its unique position in the research and development community. Research and hands-on experience is essential for NIST to make informed and impartial standards recommendations.

Recognizing the importance of manufacturing interface standards, NIST decided in late 1980 to establish a research facility to investigate critical issues in factory automation standards. The first major goal of the Automated Manufacturing Research Facility (AMRF) involved the construction of a flexible manufacturing system testbed for the small-batch manufacturing environment[4]. The AMRF consists of a set of six manufacturing workstations that occupy a 5000 square foot area in the NIST machine shop (Figure 1). The workstations perform horizontal milling, vertical milling, turning, cleaning and deburring, inspection, and material handling (using robot carts).

The facility is being used as a laboratory by government, industry, and academic researchers to develop, test and evaluate potential interface standards. To ensure that the system interface issue is addressed, the testbed is designed to contain component modules from a variety of vendors.

A major goal of the AMRF has been the transfer of resulting technology to industry. Technology findings have been transferred to the private sector through the NIST Industrial Research Associate Program[5], participation of staff in factory standards organizations, conference papers, technical reports, staff visits to industrial sites, public demonstrations of AMRF technology, and various other transfer programs established with sponsors and participants.

The AMRF has made a fresh start with respect to factory automation and in developing an architecture on the basis of fundamental principles [6]. The generic factory architecture incorporates elements such as (a) hierarchical facility control,

(b) distributed database management, (c) communication network protocols, (d) on-line process control (deterministic metrology), (e) data (and feature) driven processes, and (f) manufacturing data preparation (e.g. design, process planning, and off-line equipment programming).

The inclusion of the National Bureau of Standards in the Omnibus Trade and Competitiveness Act of 1988 attests to the success of the AMRF. Besides the change of the organization's name, the mission of the new Institute was expanded to include an emphasis on technology development and transfer. The AMRF was cited as a research and development program whose results should be made available to mid-to-small sized businesses that could benefit from this technology. This has led to the Manufacturing Technology Centers Program [7] which has plans to establish technology centers throughout the United States with the role of "hardening" AMRF and similar advanced manufacturing technology.

It is this experience of (a) building a large scale testbed facility, (b) working with industry and universities, (c) studying standards issues, and (d) implementing solutions that brings NIST to an important role in the implementation of PDES.

ENGINEERING RESEARCH PARADIGM

In the past, engineers have been concerned with "things" and their measurements. Modern technology requires more concern for "information" and ways of exchanging information. As a recognition of the key role of information management in the development of engineering systems as a whole, NIST has developed the "Engineering Research Paradigm" (Figure 2) as a model for the appropriate NIST role in carrying out projects.

The NIST engineering research paradigm consists of four major components: (a) system specification, (b) information management technology, (c) engineering technology, and (d) engineering application. The paradigm starts with an industrial need for which it is appropriate for NIST to have a role. In general, the need is associated with a specific product type (e.g. mechanical, chemical) and a specific application (e.g. flexible manufacturing systems, robot handling.) The major task for NIST is to lead the industrial community in the development of a new set of standards that will result in the production of world class products. The standards include an information model representing the product data requirements, and a functional model representing the architecture needed for implementing new technologies related to the desired application.

In addition to standards, NIST outputs include technology concepts (e.g. new database management techniques, design optimization methods, hierarchical control theory, innovative process measurement techniques) that are passed to the public

through publications and direct interactions. Products are produced in NIST engineering application laboratories, but these products are meant to be prototypes that serve to give credibility to the research through proof-of-concept demonstrations. The laboratories become models for specifying the research environment needed to study the concepts and architecture developed in information management and engineering technology activities.

The act of implementing the technologies gives the NIST staff the experience base for understanding the standards issues. The staff can then use this knowledge to work with the appropriate standards organizations (serving in the capacity of a neutral agency) to facilitate the implementation of the standards.

The four components of the NIST engineering research paradigm are described in the following subsections.

System Specification

The function of the first component, system specification, is to identify industrial needs and develop the information and functional specifications required to solve them. These specifications become the basis for the development of the information and engineering technologies required to implement a solution to the industrial needs. Most of the activities performed in this component are involved with the voluntary national and international standards programs. The following are typical tasks to be performed:

* Identify the standards organization (or create one) that is needed for the implementation of the systems specification. Set up the mechanisms for NIST staff to make contributions to the standards activity. Assist in the definition of the scope and time schedule for standards implementation.

* Determine the information knowledge required to develop the standard (e.g. information modeling, data dictionary). Develop the engineering knowledge required for the specific application (e.g. solid modeling).

* Build a mechanism for reaching consensus on the standard.

* Develop the conformance testing procedures.

Engineering Technology

The function of the component engineering technology is to convert the functional specifications into a collection of

engineering concepts and a systems architecture that can address the industrial problem. Typical outputs of this component at NIST include archival papers that describe the on-going research and system architectural specifications that lead to the implementation of experimental laboratories. The following are typical tasks to be performed:

* Define a plan for developing the technology. This includes decomposing the overall problem into a series of tasks and specifications that can be researched.

* Identify the product data requirements and measurement systems needed. Define the control architecture and process interfaces. Develop new engineering concepts to address the problem.

* Design the overall system, including the information and functional models. Define the data requirements and the means by which data is to be collected and analyzed.

* Determine which processes are needed for the given application (e.g. process planning, robot handling).

<u>Information Management Technology</u>

The function of the component information management technology is to develop the proper information management technology to process the information identified in the system specification. The important point to be stressed is that the technology (file system, relational database) must be appropriate to meet the needs of the engineering technology. The typical outputs for this component include the publication of archival papers and the implementation of the information management technologies relevant to the engineering problems. The following are typical tasks to be performed:

* Determine from the information model specification the types of data representations required. Areas of concern include the implementation of a data dictionary, the types of schemas for representing the informational relationships, and the extent to which knowledge (rather than just information) needs to be represented.

* Based on the engineering environment (i.e. flexible manufacturing system, robot control, etc.), determine what are the important characteristics of the information management technology needed. Such parameters include (a) distributed vs. central storage, (b) homogeneous vs. heterogenous computing environments, (c) version control (or configuration

management), (d) time constraints, (e) database size, and (f) security.

* Design and implement an information management system capable of handling the required characteristics as determined above.

Engineering Application

The fourth component engineering application is the prototyping of the concepts and architecture defined in the two components, Information Management Technology and Engineering Technology. The output of this component is products that demonstrate how the engineering and information management concepts result in a credible solution. The following are typical tasks to be performed:

* Based on the systems specification and the technology to be developed, specify the product mix to be utilized in the laboratory.

* Develop the interfaces between the information management systems and the engineering processes. Develop the interfaces between the various processes that compose the engineering application.

* Build a laboratory based on the architecture and concepts defined for the information and engineering technologies. Design and perform experiments that provide the proof-of-concept for the technologies.

It is the generally held definition that world class products are characterized by those that are of high quality (as reflected in high product performance levels and high utility and reliability in a variety of operational levels), low cost (of product manufacturing, of product use, of product maintenance, and of product disposal), and short time (for development of new product designs and manufacturing processes and for delivery of current products). A recent workshop [8] involving leading researchers in design, manufacturing, and logistic systems concluded that the use of <u>concurrent engineering</u> techniques is a required engineering approach to producing world class products. The workshop developed the following definition:

> Concurrent engineering is a systematic approach to the integrated, simultaneous design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.

A requirement of concurrent engineering is the ability to represent an object being designed in an accurate, unambiguous language. PDES is meant to support this requirement. It specifies the totality of data elements which completely define a product for all applications over the product's expected life cycle. The data include not only the geometry, but tolerances, material properties, surface finishes, and other attributes and features that completely define a component part or an assembly of parts.

NIST AND THE PRODUCT DATA DRIVEN ENGINEERING PARADIGM

The combination of the need for advances in concurrent engineering technologies and the need to represent engineering data in a standard format (PDES), is a perfect industrial problem to be implemented using the NIST paradigm. In fact, over the last four years there has been a program at NIST designed around the concept of using a laboratory environment to study the technology issues relating to the manufacturing engineering application aspect of PDES.

System Specification

For the product data driven engineering application, system specification is defined as the development of the PDES/STEP standard as an ISO data exchange standard and the implementation of application protocols that specify the engineering environment in which PDES is to be used.

NIST is involved in two ways: (a) Participation in the formal standards organization, and (b) Research and development in the conformance testing procedures for PDES.

NIST staff serve as chair of the volunteer IGES/PDES Organization. In this administrative role staff perform the following functions:

* Management and configuration control of both the IGES and PDES/STEP documents.

* Balloting, recording and tracking technical issues for IGES and PDES/STEP.

* Administration of IGES/PDES membership and coordination of quarterly meetings, including those involving ISO.

* Publications of ballots and other relevant documents.

* Management of IGES and PDES/STEP test case libraries including links to conformance testing laboratories.

NIST staff also have active participation on the technical committees within the IGES/PDES Organization where the research into the development of robust information models that define the scope and application of PDES is performed. A prerequisite for participation is an experience base in understanding the product data requirements and their interrelationships over a broad range of applications. Information technology tools such as information modeling languages, data dictionaries, and database management systems are used in these efforts.

An important technical issue has been the concern over how to integrate the various information models, that represent different applications and modeling techniques. A second issue is how to store the PDES information in a structure that is independent of the data management implementation. The data dictionary system can manage the enterprise data and data semantics for use in PDES implementations (Figure 3).

NIST scientists have been involved in the approved Information Resource Dictionary System (IRDS) standard being developed by ANSI and how it can be applied to PDES[9]. There are five parts to a program that addresses the application of IRDS to PDES:

* Build a schema for a PDES IRD, using an IRDS schema extendibility feature to support the storage and management of the diverse conceptual models built by the PDES committees.

* Extend the PDES IRDS schema to support a full three-schema architecture, and populate the IRD with PDES information.

* Develop automated or assisted translation between diverse data models and represent these data models in IRDS.

* Interface PDES IRD to available software such as conceptual modeling tools and database management systems.

* Develop relationships to physical design for PDES.

NIST staff have also been involved in identifying the application of geometric modeling to the definition of PDES and its application implementations. There are many technical issues:

* Interaction between different modeling geometry systems. As an example, for NURBS (Non Uniform Rational B-Spline) surfaces, how to go from a 5th order curve to a series of 3rd order curves. In general how

is geometric information exchanged between constructive solid geometry, boundary, and wireframe.

* Topology and its relationships to geometry.

* Geometry and topology and their relationship to application areas such as numerical control (N/C) coding, graphics display, collision detection, etc.

An overriding issue is the problem of deciding what type of geometric modeler is appropriate for a given application. Research into how to categorize modeler parameters and measure expected performance for applications such as inspection and N/C coding is also important.

Throughout its existence, NIST staff have participated in the development of conformance testing procedures for industrial products. We have developed test plans that identify the approaches, methodology, resources, and tasks required to test and validate PDES (Figure 4). There are four stages to the testing: (a) topical models, (b) integrated product information model (IPIM), (c) physical file structure, and (d) PDES implementations.

There are many common testing methods that will be explored including: (a) test data file, (b) walk-through, (c) syntax analysis, (d) semantic analysis, (e) instance tables, (f) ad hoc database queries, (g) prototype application, and (h) exchange via PDES translation.

We plan to build a <u>National PDES Testbed</u> (see Figure 4) at NIST where testing of the specification and implementations can be performed. In time, the testbed will become a model for future testbeds that will be established throughout the world. To test the implementations, an application must be used, and the AMRF will serve in the area of mechanical part product testing. The testbed will also serve as a model for the type of software and hardware configurations and personnel resources needed to test and implement PDES.

<u>Information Management Technology</u>

This component is concerned with the conversion of PDES into an information management system that can support the engineering requirements. Technology involved in this component falls into the three areas of information modeling, data dictionaries, and database management systems. Important tasks to be accomplished involve (a) developing an overall "framework" that integrates the three information technologies, (b) implementing the appropriate information systems that are based on the framework, and finally (c) assuring the successful use of the framework by its acceptance as an international standard.

The implementation of PDES has been defined in terms of four levels:

* Level 1: Passive File - The simplest level of implementation involves the transfer of complete sets of product information as a passive file (typically a magnetic tape). Specialized translators embedded within applications are usually required to create and subsequently read the data. This is currently the way IGES is implemented.

* Level 2: Active File - At this level of implementation applications may use in memory "active" versions of the data file(s). Generic parsers and query mechanisms may be shared among many applications.

* Level 3: Shared Database - Applications may make requests for the data they require to a centralized product database.

* Level 4: Knowledge Base - A centralized or distributed database which contains an object oriented form of the product. The "knowledge base" capability stems from the capturing of constraints and behavior of the various entities and embedding this behavior in the data structures contained in the entities.

The requirements for a concurrent engineering environment can be categorized as follows:

* Integrated and continuing participation of multifunction teams in the design of product and processes.

* Flexibility to evolve the engineering, manufacturing, and support processes.

* Widely distributed teams.

* Open and continuous communication between customer and vendor.

* Intelligent oversight for impact assessment of changes and proactive availability of designs.

* Automated policy enforcement.

These requirements lead to the level 4 knowledge database as the appropriate implementation. The technology developed in this system must demonstrate that an object-oriented knowledge

database containing an integrated product definition can provide to application programs unambiguous product characteristics that do not require human interpretation, and do so independently of a particular environment. (An interesting approach to a technical solution was described in the OPIKA program plan[10].) The database will consist of persistent, complex data objects and incorporate an inference process that can be maintained and accessed. The application programs will query the knowledge database and retrieve information required to accomplish specific life-cycle functions.

The level 4 system architecture is based on the three schema approach (conceptual, internal, and external schemas) and should demonstrate:

* a general method of assuring unambiguous part descriptions.

* a conceptual product and process definition data model that supports a range of life-cycle functions.

* a direct method to convert the conceptual product and process definition data model into an operational, object-oriented, inference process knowledge database.

* methods to manage this knowledge database.

* methods to provide access to this knowledge database platform from life-cycle application programs.

Such a knowledge database system requires a careful integration of PDES data models, described in an information modeling language (e.g. IDEF1X - developed by the Air Force Mantech ICAM Program), the use of a data dictionary (e.g. IRDS as defined above) to represent the 3-schema data[11], an object-oriented database system to represent the rules, and a product/process modeler. In addition, there is the issue of distributed databases and communication networking protocols in support of the separated computing environments. The combination of all these issues can only be resolved with a standard information framework that integrates the subsystems. Without a standard, different companies will implement unique frameworks that could be incompatible. This would make it impossible for concurrent engineering to exist across company boundaries. Not only does there need to be a standard framework, but the subsystems need to be defined as standards. For example, the Department of Defense, through the Computer-aided Acquisition and Logistic Support (CALS) Program, is trying to implement a framework for a Contractor Integrated Technical Information System[12].

Engineering Technology

This component is concerned with the development of technologies that represent the processes within concurrent engineering. The life-cycle engineering system represents an integrated set of individual functions: design, planning and programming, production, deployment, operation, support and maintenance, and recycling and recovery. Major technical building blocks that scan these life-cycle functions include: data requirements, tools & models, manufacturing systems methods, geometric dimensioning & tolerancing, and design processes.

The data requirements describe the specific kinds of data needed to create and evolve the product and the manufacturing processes. This information is exactly what is defined within the scope of PDES. The major task is to develop the application protocol interfaces between the PDES knowledge database and the life-cycle processes (Figure 5). A specific example would be to define the types of data required by a product designer and how it should be captured and stored.

The tools and models are used to measure such things as manufacturability, design "goodness," estimation of product and process performance and cost, projection of impact of changes from one alternative design to another, and manufacturing configuration. The following are some examples of needed engineering tools and models:

* Process models are developed for various manufacturing processes such as metal cutting, forming, injection molding, casting, and soldering. They are used to alter product geometry or process parameters through various engineering, geometric, statistical and scientific analyses. The models can provide a measurement (such as tolerances, material integrity, strength, and surface finish) for projecting process performance (such as speeds, temperatures, and precision).

* Assembly and cost models provide the designer with an estimate of cost prediction and design options for more easily assembled products. Geometric models of position and path for product handling are also useful.

* Manufacturing system models measure the capacity of systems. The integration of capacity and capability models in manufacturing allows the designer to consider high strength products.

* Design of experiments and other statistical methods are used in the research into applications ranging from graphical display of data, through design of experiments, to

the application of time-series analysis in complex, feed-forward and feed-back systems are needed. Other techniques include quantification and verification of expert prior knowledge, non-linear estimations, finite element analyses, and stochastic disturbances in dynamic systems.

* Factory engineering models provide the data required by the engineer to configure the factories of the future. The tool is used to show how a decision made by the engineer to improve one process in the factory might result in simultaneous changes in data maintained in several associated applications. Some changes which might automatically occur include revisions to plant layout drawings, utility requirements, simulation models, cost/payback projections, and procurement specification documents for the proposed system.

Manufacturing systems methods relate to the integration of the design systems into the manufacturing cells and the techniques for acquiring and statistically analyzing empirical data which describe the capabilities and capacities of the manufacturing systems.

* Flexible manufacturing cells define a high level of flexible automation, especially in the areas of material removal, assembly, and inspection. Research includes the translation of design descriptions into manufacturing processes and control programs. The future systems will be "intelligent machines" that receive product descriptions, automatically interpret that description, and perform the appropriate machine operations to achieve the desired product geometry, tolerances, and material specifications.

* Production process technologies are used in the development of new manufacturing technologies for such areas as composites processing, semiconductor manufacturing, and ceramic materials processing.

* Process Measurement and Control involves measuring not only product parameters but also changes in process control parameters. The most common method used is statistical process control.

Geometric dimensioning and tolerancing plays an integral part in the entire manufacturing process. A better understanding of how to convert functional requirements of a product into acceptable dimensioning and tolerancing is required in support of concurrent engineering techniques.

Design process involves research into understanding the design process itself. An important concept is to allow a state of uncertainty to exist in the design selection by permitting a full

evaluation of alternatives to be completed. This delay is important because it is a well-known fact that 80% of the total life-cycle cost is frozen by the end of the design phase.

This engineering technology component will result in an architecture representing the results of all the technology research. One important element will be the Design Workstation (Figure 6). The concept of the workstation involves the integration of the design tools with the decision databases (consisting of design rules, life-cycle process models, feedback data, and performance measurements) so that the designer can develop the optimum product specification as represented by the PDES database.

Application Technology

This component is the laboratory in which the architecture and concepts developed in the information management and engineering technologies components are implemented. Facilities that represent processes that are part of the product life-cycle will be built and experiments will be conducted to test the technology concepts.

At present, the AMRF can be viewed as the application technology laboratory for the subset of the product life-cycle that addresses the design, manufacturing and inspection processes. There are existing projects in manufacturing data preparation, process control, and factory control that address the engineering technologies for flexible manufacturing. There are also existing projects in data management and network communications that address the information management technology issues.

The factory control system is used for the manufacturing and inspection of parts designed using a PDES format[13]. The systems are all data driven. In fact, the vertical workstation is driven from an off-line programming environment that starts from a set of machinable features for a part[14]. The inspection workstation is driven from an off-line programming environment that generates a CAD database of the part with respect to the necessary tolerance information[15]. The five level control architecture developed within the AMRF has become a major model for the implementation of manufacturing systems throughout the world. The control architecture should be extensible to other processes in the life-cycle and to other product applications.

Research in process control is being performed on many of the machine tools with particularly important results at the turning workstation[16]. The Automated Production and Technology Division and Precision Engineering Division in CME are proving the concept of "Deterministic Metrology." This theory states that if a process is performed correctly, then the product will be produced correctly without the need to inspect the product.

The application of this concept involves the complex instrumentation of a machine to feedback parameter data into a predefined process model that will result in real-time corrections to the process to stay within allowable limits.

A common thread through all the processes (design, process planning, and off-line programming) is the need for standardized methods of handling data. The objective of the Manufacturing Data Preparation research is to develop and test a seamless architecture based upon plug-compatible modules which streamlines the preparation of data for automated manufacturing systems.

At the AMRF, incoming part descriptions are converted to AMRF Part Model Files using commercial CAD systems and special software developed at the AMRF[17]. The AMRF Part Model File includes 3-D geometric and topological information, tolerances, and other data on the part in a uniform format that can be used by other AMRF systems. At the present time, translators have been written to convert this format to PDES.

Working from the PDES files, and other information in the database system, operators then prepare "process plans" for the part. In the AMRF, these computerized plans include the cell's "routing slip," which is used to schedule the movement of materials and the assignment of workstations; the workstation "operation sheets," which detail the necessary tools, materials, fixtures, and sequences of events, and the machine tool's "instruction set," which guides the tool through the motions required to shape the part. Research is being conducted into the development and testing of a single set of standard data formats for process planning at every level of the factory control hierarchy, and an editing system to generate, archive and update these plans[18].

Off-line programming is performed for the vertical workstation from a collection of machinable features and for the inspection workstation from the CAD database as described above. In addition, the Robotics Division in CME has developed an intelligent real-time control system for driving the actions of industrial robots for material handling and cleaning and deburring operations[19].

The data management project provides the basis for a PDES level 3 implementation. The AMRF approach to handling data is to allow the user the freedom to select computers and database software and still be able to build an "integrated" system. Ideally, a factory control or planning system should be able to request the information it needs without knowing which of several databases holds the information, or what format is used to store the data. A distributed database management system called the Integrated Manufacturing Database Administration System (IMDAS) has been created that meets this need[20]. IMDAS handles the

administrative tasks of generating and storing new data, accepting requests for old data, locating and updating that data, and transferring the result. IMDAS uses a "data dictionary" (to locate the required information), and a standard "Language" to manipulate data and to make requests for data (Figure 7).

The AMRF data communications system allows computer processes such as control programs to run on many different computers and to be developed using different languages and operating systems. This system uses a method of transferring information which is fast, accurate, reliable, and independent of the actual physical location of the machines. This is accomplished through the use of computer "Mailboxes," which are areas of shared memory on various computers to which all machines have access through the network communications system, subject to strict protocols[21]. Communicating control processes leave "messages" for each other and stop to read their own "mail" at opportune times without interrupting each other.

PROJECTS IN THE NIST FACTORY AUTOMATION SYSTEMS DIVISION (FASD)

At all levels of the paradigm, an important feature is the planned interaction with other institutions. NIST functions as an open facility working closely with industry, universities, other government agencies, industrial associations, and the general public on standards- and technology-related problems. The system resources available within the laboratories are the result of the combined efforts of all types of partnerships.

This section describes the technical program of the Factory Automation Systems Division, located within the Center for Manufacturing Engineering at NIST. Support in this program is obtained from other organizations at NIST that have expertise in technical aspects relating to PDES. The program will be defined in terms of the Engineering Research Paradigm.

Each of the four PDES implementation levels have a corresponding engineering application that is relevant to that implementation. It is the Division's objective to explore each of the four levels in the order from simple to complex technologies. Using this approach, the PDES data structures will be easier to analyze as well as test for conformance to the standard. Engineering applications will be utilized that are appropriate for each level.

At present, the division's program focus is mainly in the area of manufacturing, although a small start has been made in design. The projects, all of which can be regarded as efforts in product data driven engineering research and development, are funded primarily through other government agencies. The overall division budget is approximately $7.5M including $900K of NIST internal funding.

CALS Standards Support

The objective of the Office of the Secretary of the Defense (OSD) Computer-aided Acquisition and Logistics Support (CALS) program is to establish an integrated set of standards and specifications for the creation, management, and exchange of product development and logistic data by computer. The Defense Department believes that these standards will reduce substantially the cost of procuring and maintaining parts and systems.

The NIST has been funded by the CALS program from the beginning of the CALS effort. The National Computer Systems Laboratory (formerly the Institute for Computer Sciences and Technology) acts as the program manager for NIST and is involved in many of the standards activities within the program. The Factory Automation Systems Division has a strong involvement in the CALS effort in the standards that impact manufacturing engineering.

In FY89, the division is performing standards-related work in the following categories: (a) global models and IRDS, (b) technical work to support standards development participation (process planning data formats, production data reports, data interchange [ANSI X3T2], and general participation [ASTM CIM purchasing, EIA 31 BCL data, EIA 31 MMS, RIA 15.04]), (c) IGES applications subsets/protocols, and (d) IGES testing. The Center for Building Technology at NIST assisted FASD in the application protocol area in terms of the 3-D piping application.

National PDES Testbed

The National PDES Testbed Project is being funded by the Office of the Secretary of Defense (OSD) Computer-Aided Acquisition and Logistics Support (CALS) Program. Part of the CALS effort is the development of a neutral product data definition of weapon systems' parts. The PDES efforts have been supported in many ways by the CALS program. Specifically, the testbed project was initiated to support five major functions: (1) ensure standards compliance, (2) demonstrate applications of PDES technology, (3) integrate a national network of testbeds, (4) coordinate government activities, and (5) establish a program for technology transfer, testbed information consolidation and dissemination.

The principal emphasis for the first two years of the project is to work closely with PDES, Inc. The goal of this Industrial cooperative is to develop and test an initial implementation of PDES aimed at mechanical parts for a level-2 PDES implementation architecture. The PDES testbed staff are involved in the three major activities of the project which includes (a) model development and integration, (b) software products and configuration management, and (c) testing and validation.

A major result of this interaction is the early development of a complete PDES testing and demonstration facility which includes the necessary hardware and software to perform the overall testbed functions effectively. An important part of this resource has come in the form of no-cost loans of equipment and software from companies interested in the development of PDES.

Accelerating Development of the PDES Standard

The Department of the Navy (through the Office of the Assistant Secretary of the Navy for Shipbuilding and Logistics) is supporting the PDES efforts in the following manner:

* adminstration of PDES standards work - The support for NIST brings the necessary national focus to the work. Included are management, travel, meetings, editing, and printing activities. The standards activities are unusually important because of the fragmentation and the magnitude of the task.

* validation and testing - The evolving standard will need to be tested for completeness, efficiency, and consistency. Implementations need to be tested for conformance to the standard. Validation and testing procedures should be developed as the standard is being developed, for in this way lessons learned can be folded back into the standard.

* implementation support - Establishment at NIST of a central information store of all PDES-related materials and development of mechanisms for disseminating that information will increase the speed with which vendors can make and users can buy PDES implementations once there is a standard. A particular technology being explored is "hypertext;" it is being applied as a new way of describing standards as "Hyperstandards"[22].

PDES for the Apparel Industry

There are numerous vendors supplying computer aided apparel design and pattern making equipment. Each vendor's equipment represents the design and pattern data in a unique or proprietary file structure. This prevents the exchange of data among different organizations with different equipment. The Defense Personnel Support Center (DPSC) is a Defense Logistics Agency (DLA) organization that is responsible for supplying patterns to government contractors. Currently, DPSC receives the garment patterns from the military design activities as a paper product. The pattern must be manually digitized if it is to be stored as a computer file since the military departments use different design systems. In addition, if a government contractor wants to use numerically controlled cutting, the paper patterns which are

provided by DPSC must be re-digitized at the contractor's facility. This process is time consuming and prone to error.

The objective is to eliminate the unnecessary and error-prone process of re-digitizing patterns by taking advantage of work done in hardgoods for PDES and to formulate a plan for a full implementation of an Apparel Product Description Exchange Standard (APDES) that includes all attributes required to design and manufacture a garment (Figure 8).

The division will be working with several universities already receiving funding from DLA (North Carolina State University, New York Fashion Institute of Technology, Georgia Tech, and Clemson University). In addition, the division will be working closely with the American Apparel Manufacturers' Association (AAMA) in the establishment of a standard.

Manufacturing Research Testbed

The Information Systems and Technology Office (ISTO) of the Defense Advanced Research Projects Agency (DARPA) has, as one of its programs, "advanced CAD tools and their integration into machining and forming practice." There are several universities participating in this particular program. Stanford University's activity is called "concurrent product and process design." The University of Utah has a program called "geometric object description for machining." Purdue University's (with basic funding as a NSF Engineering Research Center) program is called "quick prototyping of mechanical parts; automated assembly technology." Cornell University has as its effort "geometric and dynamic simulation of manufacturing processes."

With DARPA funding, FASD has initiated a project called "Manufacturing Research Testbed" which is meant to address specific needs for the present ISTO program. These needs include (a) closer coupling of research efforts, (b) focusing of research efforts on key issues, and (c) exposure and dissemination of technology.

In the short-term, we plan to establish the DARPA/NIST Manufacturing Research Testbed. This includes test, integration, and demonstration of DARPA-funded systems, as well as working with the DARPA community to structure a long-range plan in information technologies for manufacturing. The long-term goal is to develop a nation-wide, distributed environment for cooperative research on all aspects of the manufacturing life-cycle.

AMRF

The Navy Mantech program sponsors more than half of the research within the AMRF. The research projects have already been

described as serving as the basis for an expansion in the future to cover more processes in concurrent engineering. The portion of the FASD effort covered by Navy funding includes the Manufacturing Data Preparation Project, Network Communications, Factory Control Systems (cell, vertical workstation and material handling), and Inspection.

PDES Technological Support

The portion of the division's research in the AMRF that is not supported by the Navy Program includes (a) distributed data management (i.e. IMDAS), (b) intelligent reconfiguration of manufacturing processes, and (c) measurement of software performance of coordinate measurement machines. These efforts are funded internally by NIST.

Tool Management

The Rock Island Arsenal (within the Department of the Army) has several flexible manufacturing systems that require an automated interface to a tool management system. The division is defining the specifications and architecture of the tool management system that the arsenal will purchase. A prototype system will be developed at NIST to help in developing the specification.

Network Consulting

The Navy, through the Institute for Advanced Micro-Electronics, is sponsoring a small program which involves NIST experts in network communications protocols (and possibly other system integration technologies) to consult on various aspects of the program.

Intelligent Materials Processing

FASD is receiving internal funding from the Institute of Materials Science and Engineering (IMSE) at NIST to develop an intelligent control system that will interface with the solidification of powdered metals experimental laboratory. The overall project managed by IMSE is funded through a combination of internal funding and an industrial consortium.

Relationship of Projects to Paradigm

It is obvious that the above division projects cannot accomplish all the objectives as defined in the Product Data Driven Engineering Paradigm. However they do provide a means of performing research in some of the technical areas and participating in the standards activities. This subsection describes how the projects fit into the paradigm.

The System Specification component is concerned with the development of the PDES/STEP standard. The funding for the participation in the formal standards organization comes from two projects: CALS Standards Support and Accelerating Development on the PDES Standard. A third project, PDES for the Apparel Industry, provides the opportunity to examine a different product in order to get a better understanding of what are the real core PDES requirements that are product-independent. The standard's conformance testing activities are supported by the National PDES Testbed project.

The Information Management Technology component is concerned with the four levels of PDES implementation. The National PDES Testbed project is presently concerned with the level-2 implementation as part of its cooperative effort with PDES, Inc. The PDES technical support subproject "Distributed Data Management" involves research into the required level-3 information architecture. The Networking Consulting project provides the opportunity to pursue the technical issues relating to network communications for manufacturing systems and its impact on information management systems.

The Engineering Technology component is concerned with the dvelopment of architectures and concepts associated with the engineering application. The Manufacturing Research Testbed project is concentrating on the tools needed to perform aspects of the "Design for the Life-Cycle" issue. The divison's portion of the Navy AMRF project is concerned with many of the manufacturing related technologies such as factory control architecture and manufacturing data preparation. In the PDES Technological Support subproject -- the intelligent reconfiguration of manufacturing processes and the tool management project, the issue of factory engineering is studied. In the measurement of software performance of coordinate measurement machines (CMM), quality control issues in manufacturing are considered. Of real short-term importance is the resolution of the technical problem associated with the ability of a CMM to reproduce the inspection capability of manual gauging accurately.

The Application Technology component is concerned with the implementation of the technologies in a laboratory environment. The Navy AMRF project provides the opportunity to test the control and metrology concepts developed by NIST technical staff. It also provides for the testing of the IMDAS architecture that supports the flexible manufacturing systems information management requirements. The Intelligent Materials Processing project is an opportunity to apply the control and information concepts from the AMRF into a very different product application -- materials processing.

FUTURE DIRECTIONS IN PRODUCT DATA DRIVEN ENGINEERING AT NIST

It is the long-term goal for NIST to expand its efforts in the area of product data standards and concurrent engineering. At present, a "NIST-wide Product Data Exchange Task Group" meets on a weekly basis to determine the present and future NIST role in PDES development. Members of the task group come from throughout NIST: (a) Center for Manufacturing Engineering, (b) Center for Building Technology, (c) Center for Electronics and Electrical Engineering, (d) National Computer Systems Laboratory, and (e) NIST Director's Office. The goal of the group is to have a representative from every engineering organization at NIST.

The long term strategy is to implement the Engineering Research Paradigm in each of the major centers at NIST. Each center would have a laboratory to study the product data requirements for a product relevant to its technical mission. All the centers would develop a core set of skills in both information and engineering technologies that are applicable to PDES and concurrent engineering issues (Figure 9).

Over the next several years, engineering research will expand from manufacturing into concurrent engineering. This research will be necessary to participate technically in the future requirements for PDES as the scope is broadened and new applications are added. The following illustrates typical examples of new research based on the present AMRF program:

Systems Specification

* Based on the experience in developing conformance testing procedures for PDES levels 1 and 2, develop similar procedures for levels 3 and 4. This activity relies on the support of the National Computer Systems Laboratory at NIST which has the experience in conformance testing over a broad spectrum of computer software products.

* Based on the experience in developing application models for mechanical parts, develop a similar in-depth application model for electrical and electronic industries that can interface with existing standards such as EDIF (EIA Electronic Data Exchange Format) and VHDL (VHSIC Hardware Description Standard). Work with the Center for Electronics and Electrical Engineering to establish the product model that will affect all of the three major activities encountered in electrical engineering: design, manufacturing, and testing. The design of electronic products takes place at many hierarchical levels. The challenge is to provide an environment for a product description where all the information is available at all levels simultaneously at the "right level" of detail. This capability is necessary to permit the modeling, prediction

of performance, and development of tests to ensure proper product design. In the area of testing, the challenge is to formulate a PDES description of electronic systems and their components such that effective tests can be generated and "proven" to exist at the design stage.

Information Management Technology

* Based on the information technologies used to develop systems in the AMRF and PDES levels 1 and 2, expand the capabilities of information modeling and data dictionaries to handle the technical issues relating to a PDES level 4 knowledge base needed for concurrent engineering. This research relies on the active participation of the National Computer Systems Laboratory at NIST that has the expertise in the appropriate technologies and standards issues. Participation by the Center for Building Technology is also desirable because of the information modeling skills presently being applied to the construction industry.

* Based on the experience in implementing a heterogeneous distributed database system (IMDAS), expand the technology into the area of knowledge bases.

Engineering Technology

* Based on the actual design work being performed by the Precision Engineering Division in CME in the development of a new device called "The Molecular Measurement Machine," create a project to capture all the design knowledge used by the technical staff in building the machine.

* Based on the experience from producing a manufacturing data preparation system that captures the required data to manufacture mechanical parts, implement a design workstation environment that can use this information to perform the designer's operations.

* Based on the experience in "deterministic metrology" for machine tools and coordinate measurement machines, develop statistical experiments in design that can be integrated with the design workstation. This research would rely on the statistical design expertise in the Center for Computing and Applied Mathematics at NIST, and the metrology expertise in the Automated Production Technology Division in CME.

Application Technology

* Based on the experience in intelligent control systems for the shop floor, and with the present interaction with the Institute for Materials Science and Engineering (IMSE) at NIST in the area of rapidly solidified metal powders and hot

isostatic pressure, develop a program in design for materials. The IMSE facilities are capable of producing a specifically shaped metal material consisting of a new molecular structure. The process is controlled by a set of known parameters.

* Based on the experience of the Center for Building Technology, construct a laboratory environment for "Computer Integrated Construction" where the PDES and concurrent engineering issues can be studied in terms of the construction industry.

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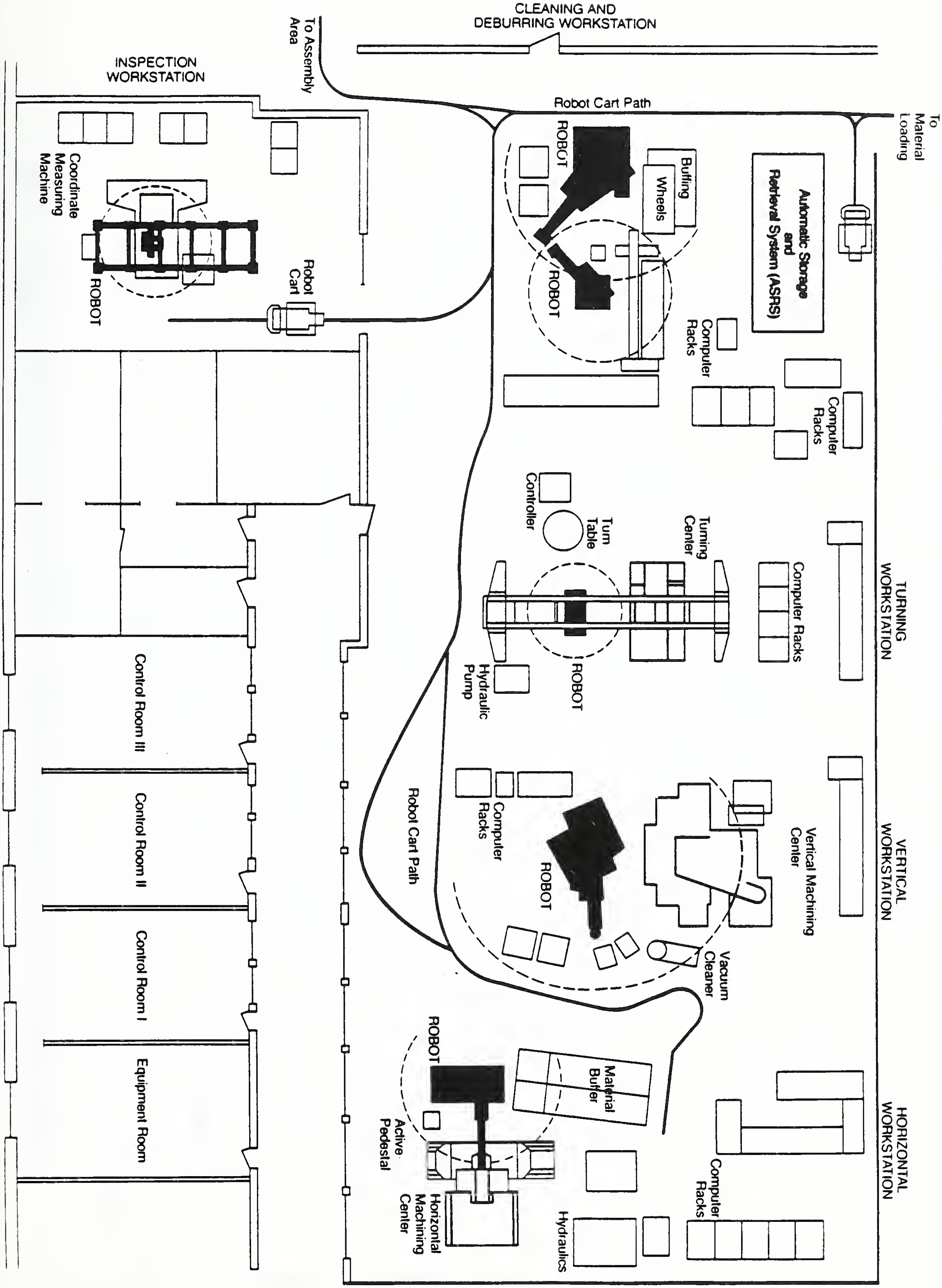


Figure 1 **AMRF Shop Floor Layout**

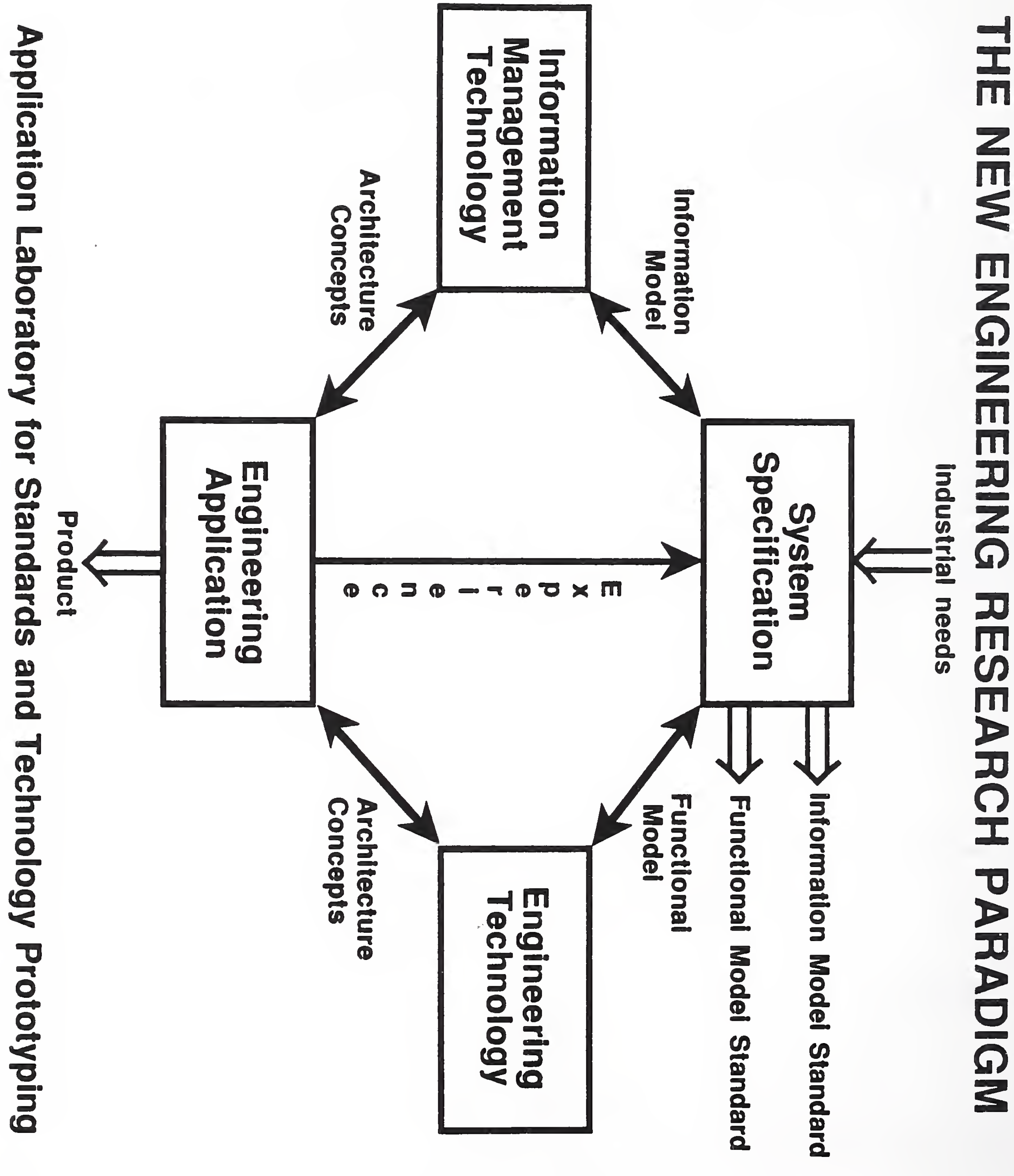
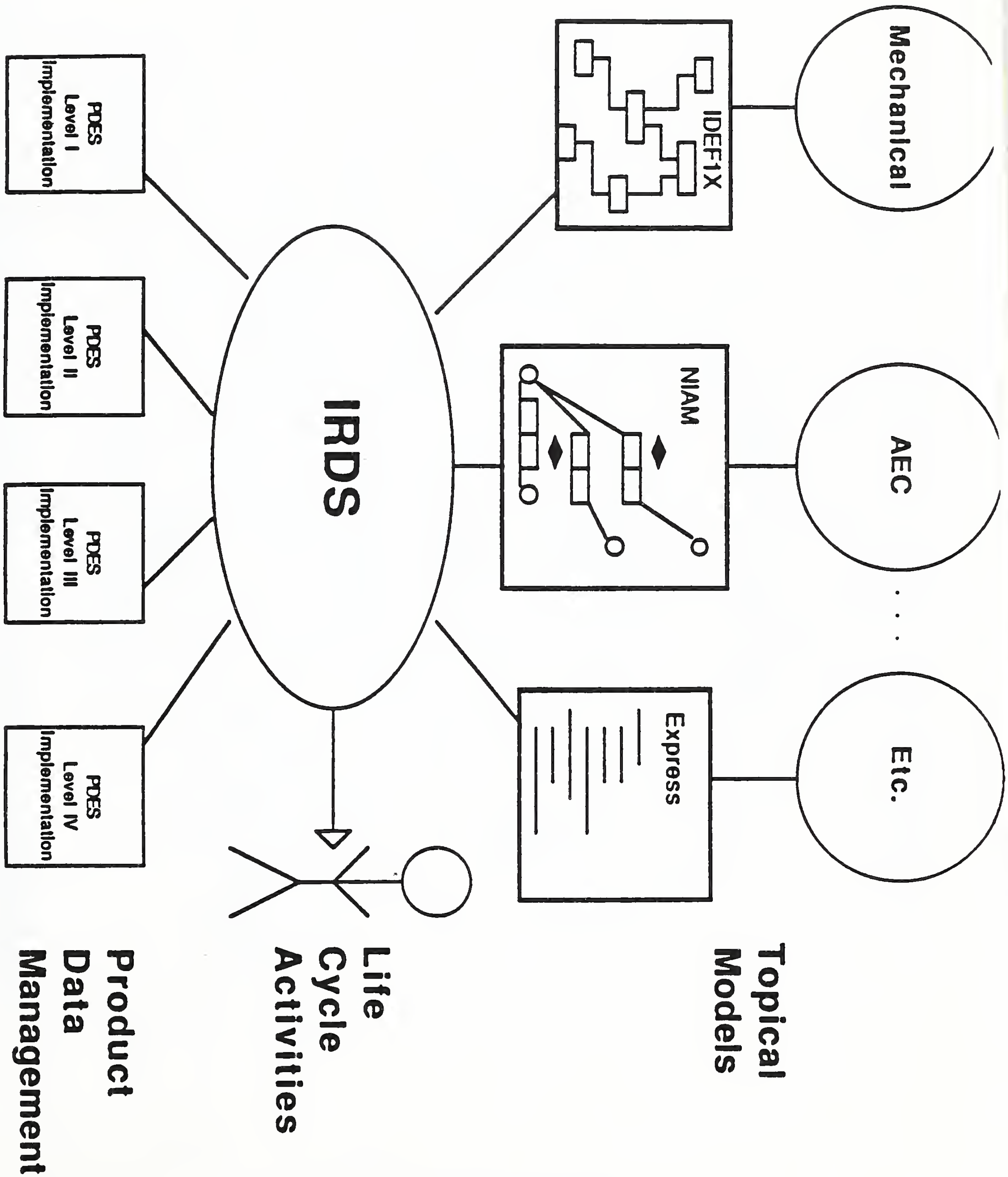


Figure 2 The New Engineering Research Paradigm



The Role of IRDS in PDES

Figure 3

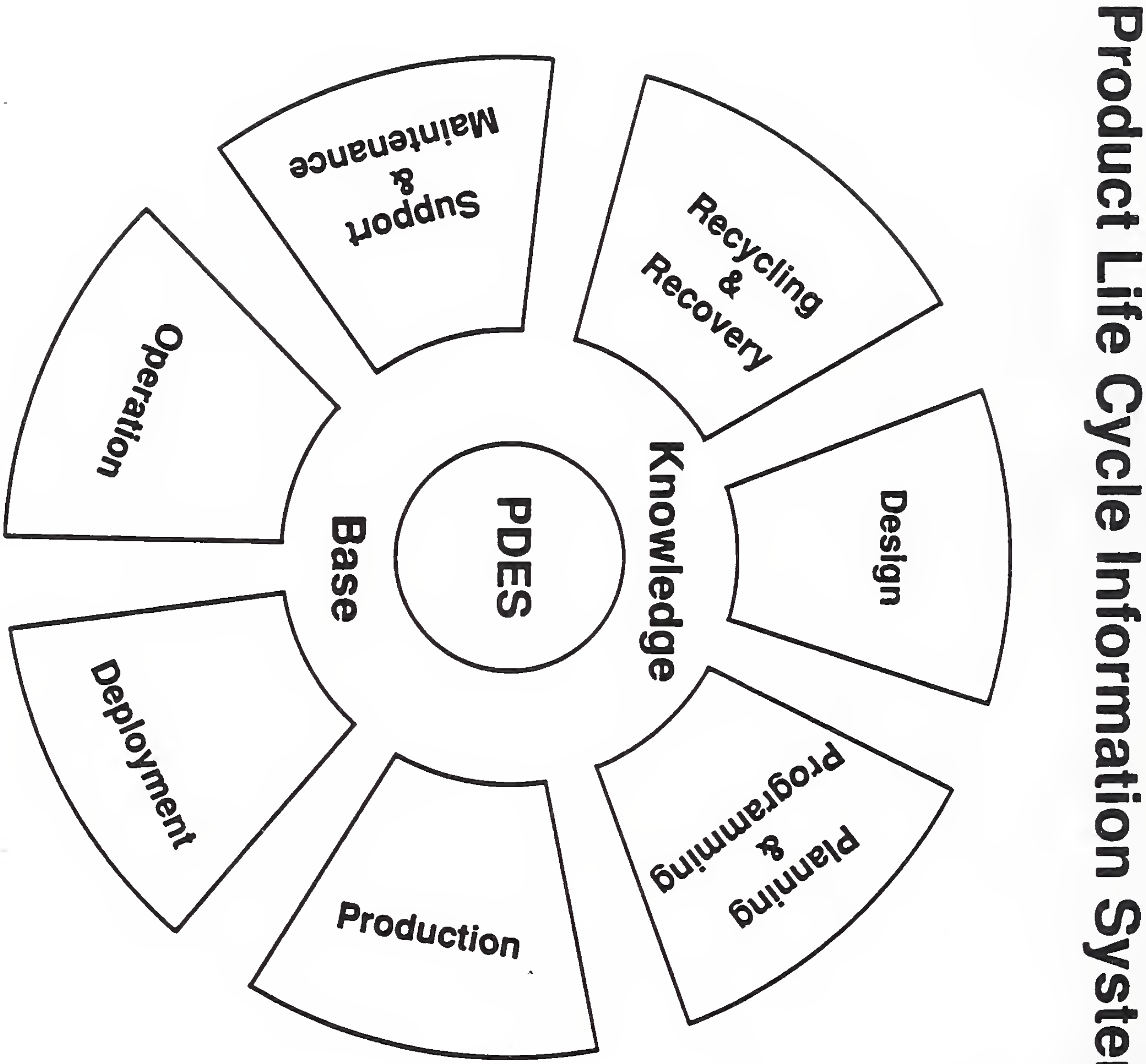


Figure 5 Product Life Cycle Information System

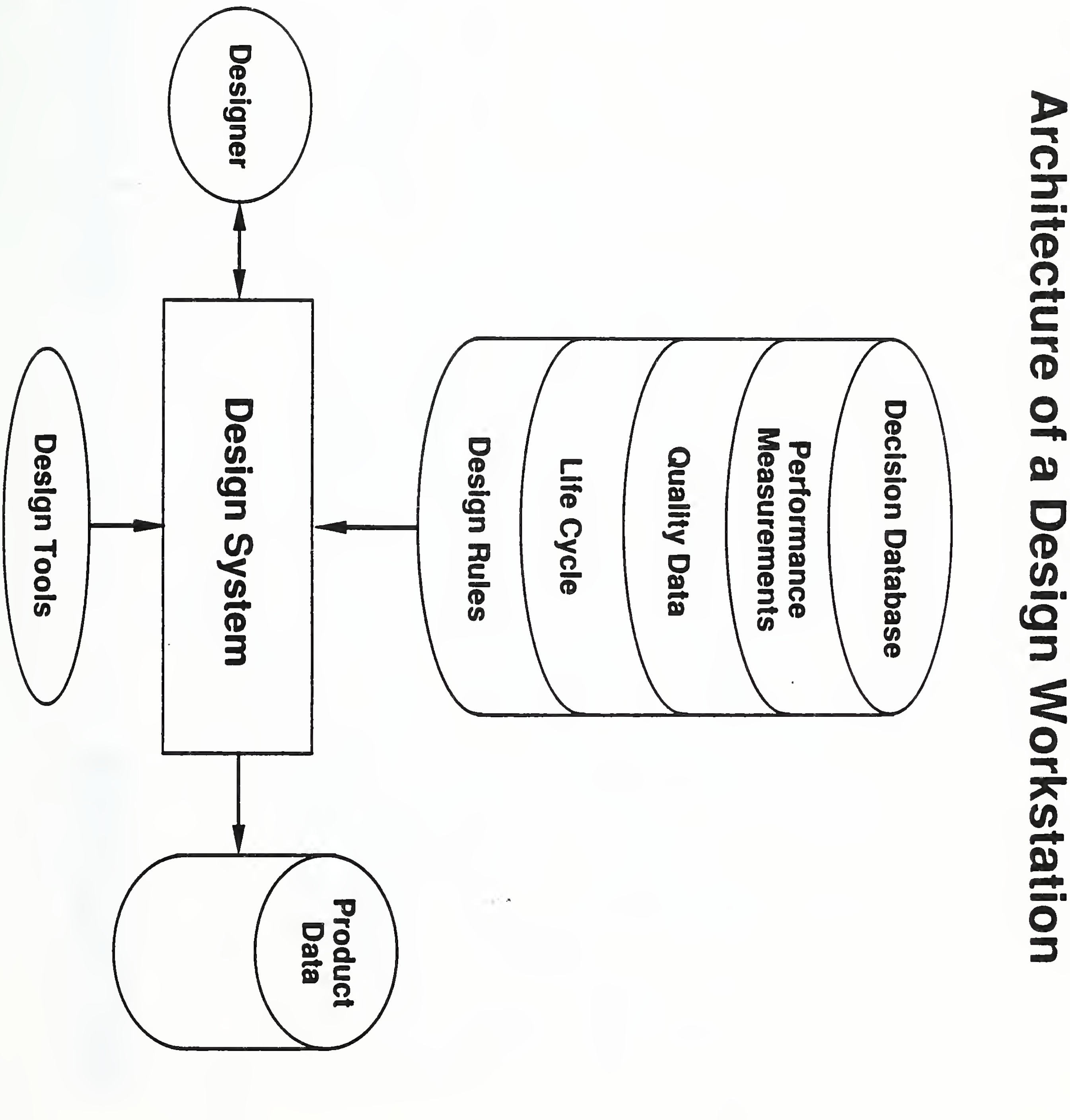
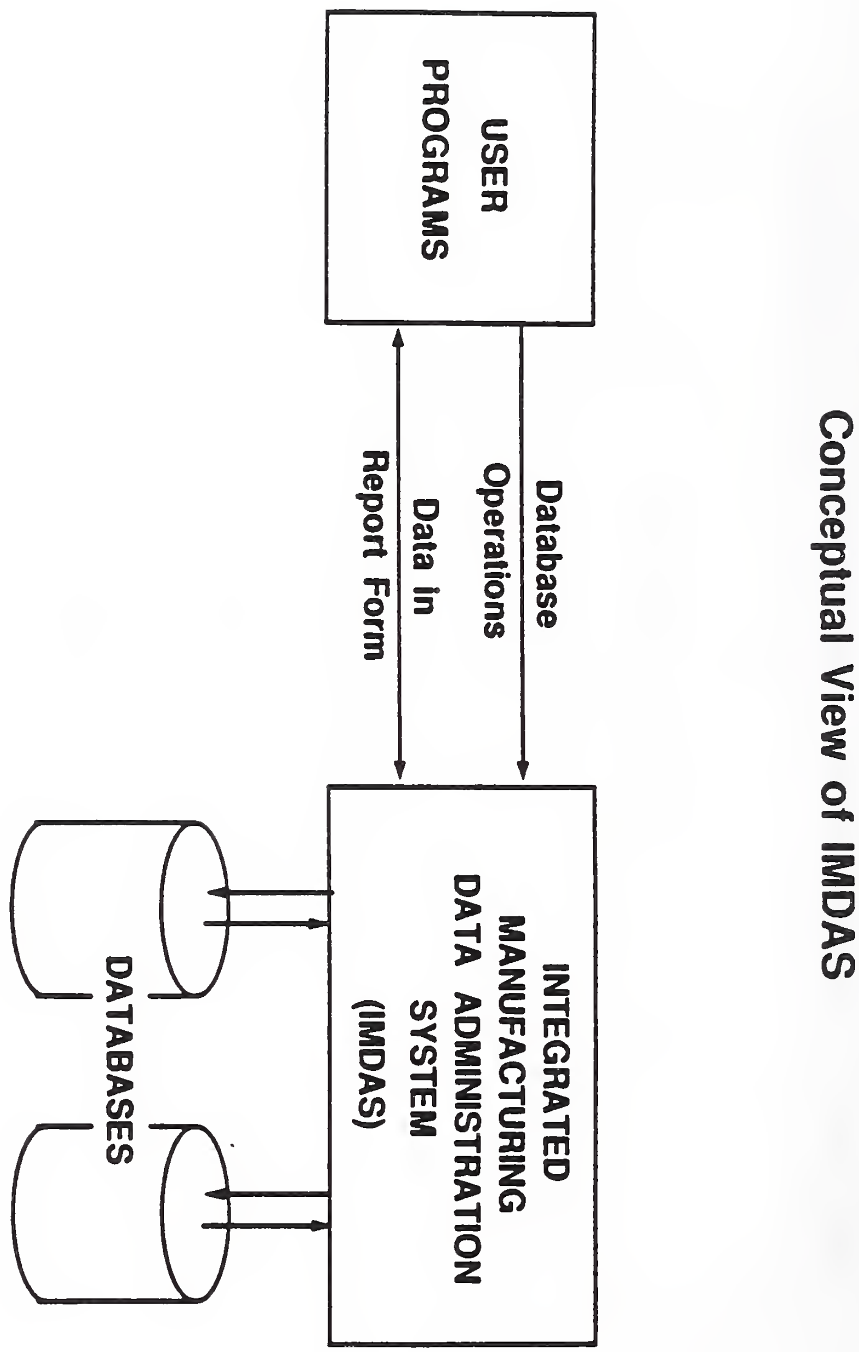


Figure 6 Architecture of a Design Workstation

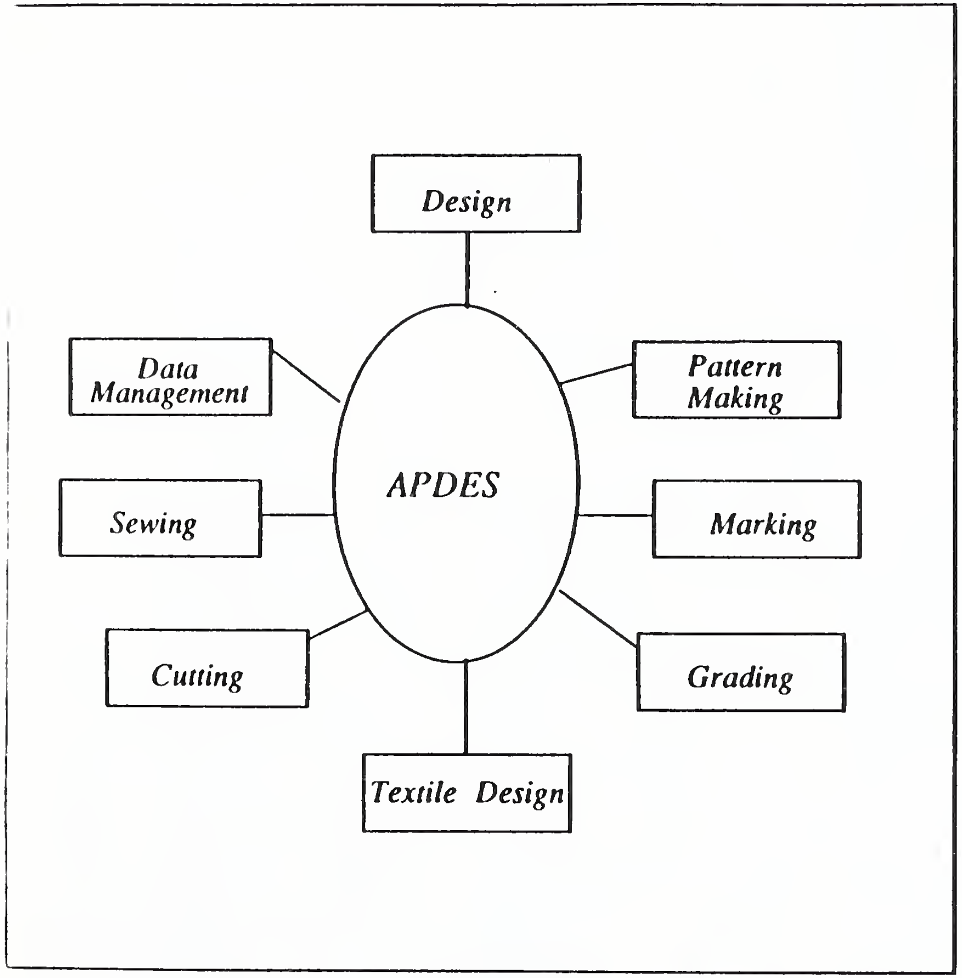


Conceptual View of IMDAS

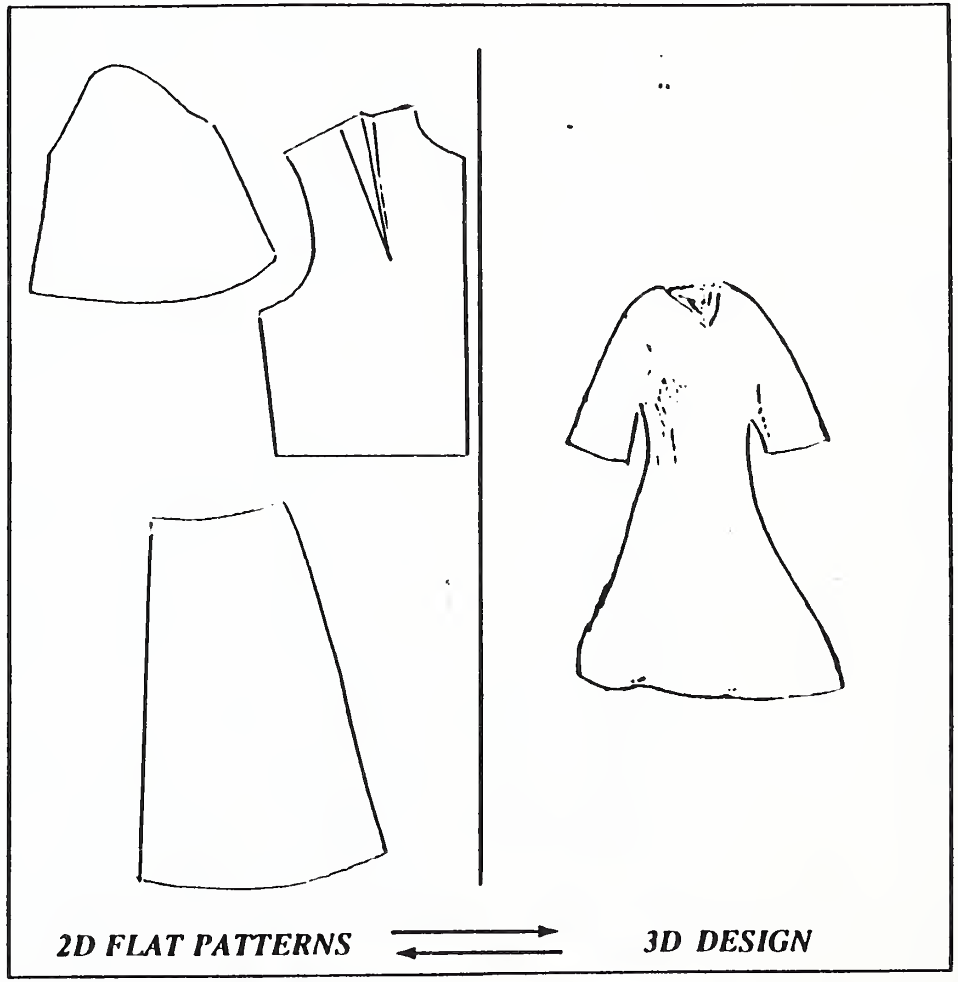
Figure 7

APPAREL CIM RESEARCH

-- APPAREL PRODUCTION DEFINITION EXCHANGES STANDARD (APDES) --



OVERVIEW

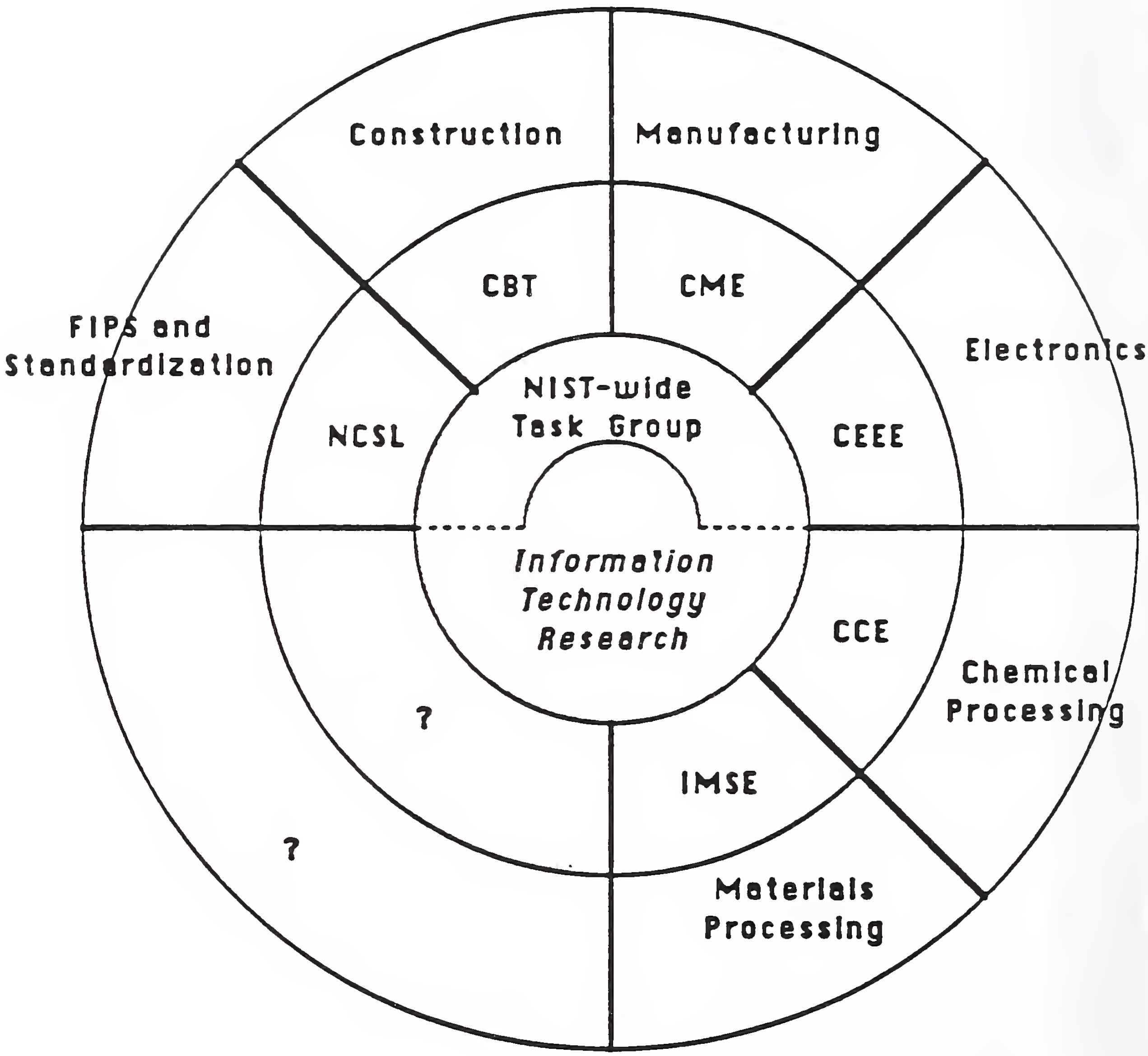


APPLICATION

Apparel CIM Research

Figure 8

The Needs of Many Industries Are Driving The Development Of A Common Research Agenda



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__ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The various activities of the National Institute of Standards and Technology (NIST) in the development of a Product Data Exchange Standard (PDES) will be discussed. The NIST activities will be described in terms of the unique position that the agency has in the area of standards and technology development in the United States. The NIST has an active role in participating in the formal development of the PDES standard. In addition, NIST is engaged in research and development programs involving information technologies necessary for implementing PDES and engineering technologies that make use of product data. Specific applications such as mechanical part fabrication are being used to provide a testbed for the validation and verification of PDES. The paper addresses how PDES can be used to implement needed technologies such as concurrent engineering that will improve American Industrial competitiveness. The combination of PDES implementations with concurrent engineering is called in this paper "Product Data Driven Engineering".

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Competitiveness, Concurrent Engineering, Design for Life-Cycle, Information Technology, Knowledge Database, PDES, Product Data, Product Life-Cycle, Productivity

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